

T-1

Mechanics of Materials & Equation-of-State

Wave Propagation in an Epoxy-Graphite Laminate

Brad Clements, Jim Johnson, Frank Addessio (T-3), and Rob Hixson (DX-1)

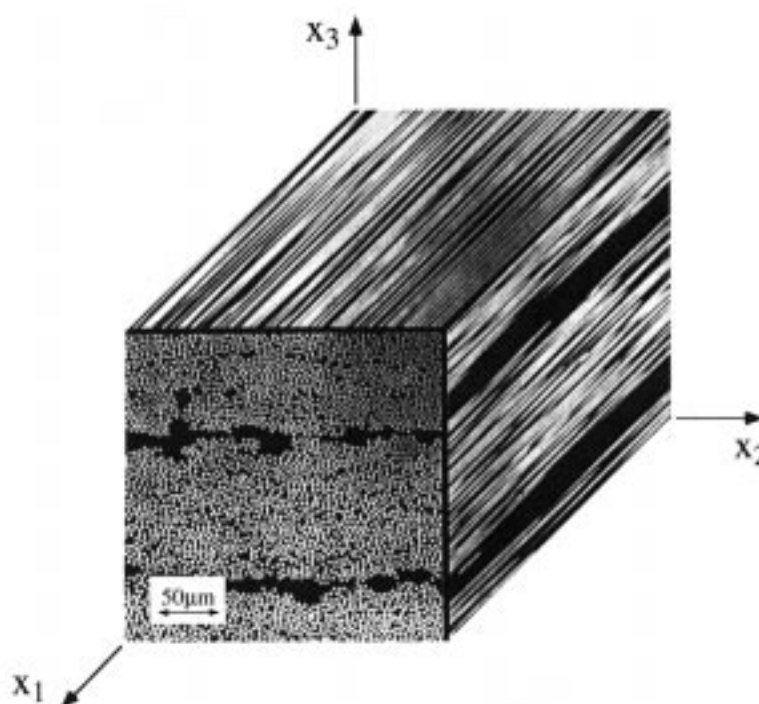
Certain material mixtures, i.e., composites, can have a desired blend of thermal and mechanical properties; while often no single material, with these same properties, can be easily identified. It is for this reason that composite research has burgeoned within the last few years. Fabricating a composite suitable for a particular application is, however, seldom an easy task. The composite designer has an almost unlimited number of variables to choose from. These variables include a choice for constituent material composition, the volume fractions occupied by each constituent, plus morphological considerations. Examples of the latter are laminates, particulate and fiber inclusions embedded in continuous matrix phase, weaves, and combinations of these.

As a consequence of the large number of variables, there seems to be a nearly inexhaustible possibility for finding novel composites with new and desirable thermal and mechanical attributes. To circumvent a large amount of unnecessary and costly trial-and-error experimentation, there is a need to develop better physical-based models as well as numerical techniques to implement these models. These tools will provide a better theoretical understanding of complex composite

systems. The ultimate goal is to be able to predict the properties of a composite by knowing the properties of the constituents, plus the chosen volume fractions and the morphology. This includes high-velocity impact and wave propagation.

Homogeneous treatments, involving standard finite-difference hydrodynamic methods and average material behavior, may be all that is required in many of these dynamical situations. However, in other cases, highly accurate numerical solutions may be needed. We have undertaken the task of developing one such method. The method is called the nonhomogenized,

dynamic method of cells (NHDMOC). The NHDMOC theory is based on an accurate ansatz for the particle displacement field, relevant equations of motion, constitutive relations, plus conditions of stress and particle displacement continuity applied to all material boundaries. It is superior to standard hydrodynamic methods in that it consistently requires considerably coarser spatial and temporal grids, and a much smaller (even zero) artificial viscosity, in comparison to hydrodynamic methods. The fact that smaller artificial viscosity is required can be expected to be very important when the theory is applied to complex heterogeneous structures where

**Figure 1**

multiple reflections and transmissions at material boundaries will produce true physical ringings that should not be *a priori* damped out of the numerical solutions.

As an example, we have applied the NHDMOC theory to model a shock-wave experiment involving a unidirectional, fiber-reinforced, epoxy-graphite laminate. The microstructure is shown in Figure 1, and a schematic of the experiment is shown in Figure 2. Constitutive relations suitable for the various materials are used in the calculation. This includes linear and nonlinear elasticity, and when appropriate, viscoelasticity. The flyer consists of a 1.557-mm Z-cut-quartz impactor backed by a 5-mm polymethylmethacrylate (PMMA) slab. The bilaminate has 19 bilayers: one layer of each bilayer is an epoxy-graphite mixture, and the second, much thinner layer, is pure epoxy. The graphite, in the mixture, is distributed uniformly throughout the layer. The bilaminate is backed by a 5-mm PMMA window. In the experiment, a VISAR (Velocity Interferometer System for Any Reflector) was used to measure the particle velocity history at the bilaminate-PMMA interface. The impact velocity of the flyer was 500 m/s. In Figure 3, the experimental and theoretical particle velocity profiles are shown. Overall, the agreement between the NHDMOC theory and the experiment is very satisfactory, demonstrating that the method provides a useful technique for such

calculations. The high-frequency oscillations are caused by the laminations in the sample. The NHDMOC theory captures, with precision, even these fine details. This example shows that as the NHDMOC method of solution is investigated further and matures, it may become the standard approach for wave-propagation calculations in composites and other heterogeneous materials.

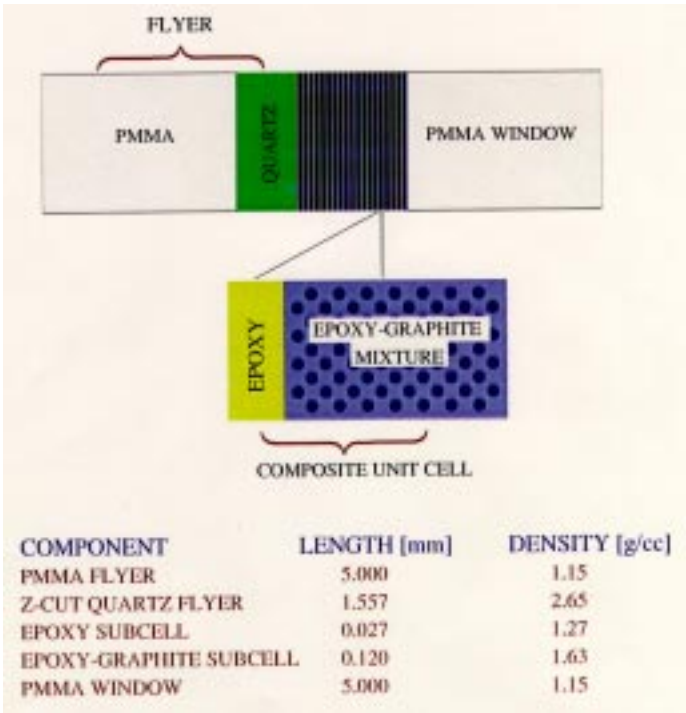


Figure 2

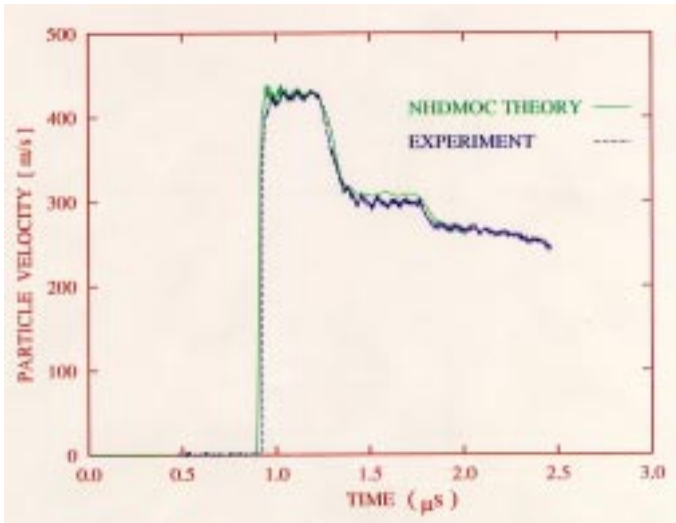


Figure 3